The Marquardt Company VAN NUYS CALIFORNIA

LEVEL II

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FINAL REPORT

SLD REACTION CONTROL
AND PROPULSION SYSTEM
PRELIMINARY DESIGN STUDY

CONTRACT N00173-79-C-0342

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I. SUMMARY

The Marquardt Company (TMC) undertook the study of the SLD Reaction Control and Propulsion System in accordance with Contract N00173-79-C0342 and the TMC proposal P81-212 in September 1979. These studies, were continued through August 1980.

In accordance with the NRL requirements and guidelines, the Reaction Control and Propulsion System has been established on a preliminary basis. The overall system has been conceived using one TMC R-40B thruster, operating at 900 pounds thrust and ten TMC R-6C 5 pound thrust attitude control thrusters. The R-40B bipropellant thruster is a modified Space Shuttle Orbiter Attitude Control Engine (the R-40A). The R-40A has been modified only slightly with resized nozzle and chamber assembly optimized for the available space in the SLD. The R-6C bipropellant attitude control thrusters qualified for commercial and DoD spacecraft are packaged in two five thruster modules attached externally to the stage structure.

In a cooperative effort with the NRL Program Manager, the propellant and pressurant systems functional design rationale have been developed to meet the assembly, launch and operational requirements of the SLD. The major effort during this study has been devoted to analysis and obtaining technical and cost data for the major components such as propellant tanks, pressurant tanks, pressurizing control valves, isolation valves, latch valves, fill and drain valves and filters.

The preliminary design of this propulsion system provides state-of-the-art design features such as:

- Fibrewound pressurant tanks to provide low cost, reasonable procurement time, lower weight and improved safety.
- Aluminum propellant tanks to provide low cost and reasonable procurement time.
- Redundant electronic pressure control subsystem to provide low weight and ensure high reliability.
- Isolation of propellant tank vapors/liquids during nonoperating intervals during the mission.
- Triple redundant isolation of the pressurant and the propellants.
- Redundant attitude control system achieved with minimum isolation valving and thrusters.

The results of this study are to be used in the design of the propulsion system and its integration into the SLD. The study also provides a basis for the preparation of component procurement specifications.

II. PROPULSION SYSTEM DESCRIPTION

The preliminary system design requirements for the spacecraft propulsion system included the following:

- Provide thrust for spin, attitude control, transfer and parking maneuvers of the SLD in space.
- Provide a minimum of 5400 lbs of nitrogen tetroxide and monomethylhydrazine propellants and a maximum of 11,000 lbs.
- Use ten R-6C Attitude Control Bipropellant Thrusters and one R-40B Delta V Bipropellant Thruster.
- Comply with Space Transportation System safety requirements.
- Withstand boost, landing and orbital environments within the orbiter cargo bay in the fueled condition.
- Provide optimal tank pressurization system.
- Provide optimal propellant orientation method.
- Provide maximum subsystem serviceability and ease of assembly.
- Provide optimal configuration approach to maximize stage mass fraction consistent with minimum overall length.
- Assume "comfortable" thermal environment in space.
- Base the system concepts and approaches on contemporary state-of-the-art technology.

From these requirements the system design shown schematically in Figure 1 evolved. It reflects experience evolved by NRL with the assembly and launch checkout operations and also TMC's experience with the design, fabrication and assembly of bipropellant systems and components.

- Helium Pressurant Subsystem

  The helium pressurant subsystem provides two parallel subsystems which independently pressurize the fuel and oxidizer tanks thus isolating the propellant liquids and vapors. Two 28.6 inch diameter pressurant tanks feed four 42 inch diameter propellant tanks (or four 28.6 inch diameter pressurant tanks feed four 54 inch diameter propellant tanks). Two high pressure transducers, two fill and vent valves, two filters, two quadredundant sets of solenoid valves and four low pressure transducers provide control instrumentation. A pressure regulating electronics package controls the solenoid valves from the output of the low pressure transducers which sense the propellant tank pressures. The pressure regulator electronics package contains parallel redundant sensing and control circuitry

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SLD PROPULSION SYSTEM

System Diagram (Preliminary)

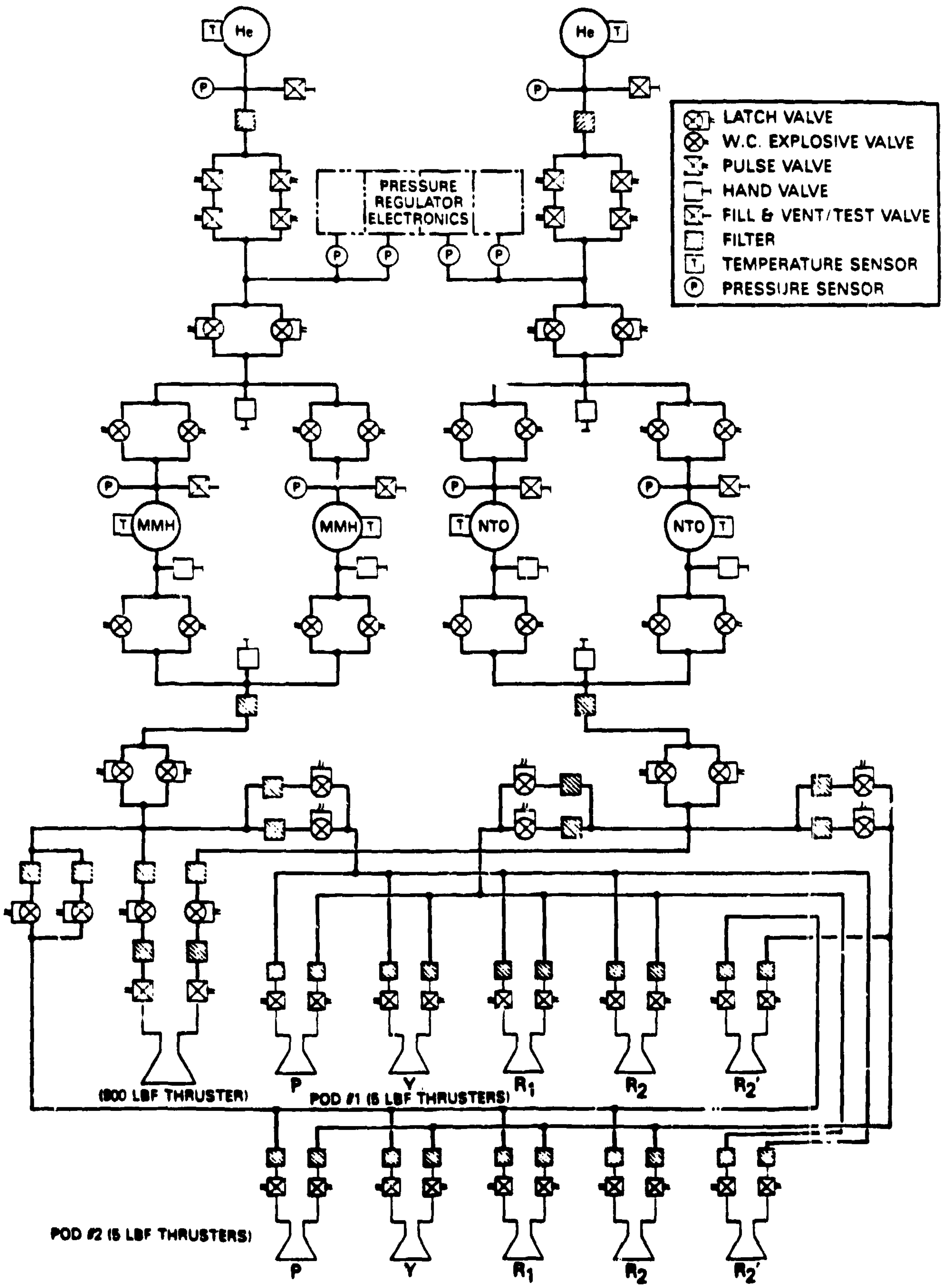

FIGURE 1

to control both the fuel tank pressurization solenoid valves and the oxidizer tank pressurization solenoid valves. An electronic comparator circuit should maintain the two sets of tank pressures within 1-1/2 psia or better under all operating conditions. A parallel redundant set of latching valves further provides protection for the pressurization solenoid valves during long off times. A vent (or instrumentation port) valve downstream of each set of latching valves is provided to allow checkout operations of each pressure regulating subsystem and the latching valves during assembly and launch checkout.

- Propellant Tank Subsystem

  For each propellant, the system consists of parallel redundant isolation valves, upstream and downstream parallel redundant pyrotechnic valves, pressure and temperature transducers, fill and drain valve, two propellant tanks (42 or 54 inch nominal diameter), and a downstream fill hand-operated valve. This subsystem is designed to allow separate leak testing, filling and checkout of each tank during ground operations. Since the tanks for each propellant are installed diagonally opposite, interconnection of the tanks prior to flight operation for filling and draining is not feasible. Further analysis of the spin, despin and parking maneuvers may indicate that the propellant pyrotechnic isolation valves should be replaced by propellant latching isolation valves.

- Propellant Distribution Subsystem

  For each propellant, the subsystem consists of an upstream inspection port valve, one primary filter feeding a parallel redundant set of latching isolation valves which in turn feeds a parallel redundant secondary filter system and latching isolation valves in each of two RCS pods containing five thrusters each, and one secondary filter and latching valve located at the vehicle centerline with the 900 lbf Delta V thruster. The secondary filters are inserted at the mechanical joints in the system and are rated compatibly with the downstream valve clearances and engine orifice dimensions as well as the filtration characteristics of the propellants. This arrangement provides triply redundant valving downstream of the propellant tanks for protection of the orbiter during launch and in cargo bay flight operation. Another feature of the arrangement provides cross connected plumbing for the redundant roll thrusters. This not only provides backup operation in the event of leakage or malfunction within an RCS pod, but also in the event of isolation valve malfunction.

An alternate system schematic is shown in Figure 2. In this system, routing the RCS pod isolation valves in parallel to the upstream (in Figure 1) isolation valve in the propellant distribution subsystem, and the deletion of the isolation valves upstream of the Delta V thruster eliminates two valves with negligible change in flight reliability while still meeting the Shuttle Payload bay safety requirements.

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ALTERNATE SAVES 2 VALVES & MEETS SHUTTLE REQ'MTS

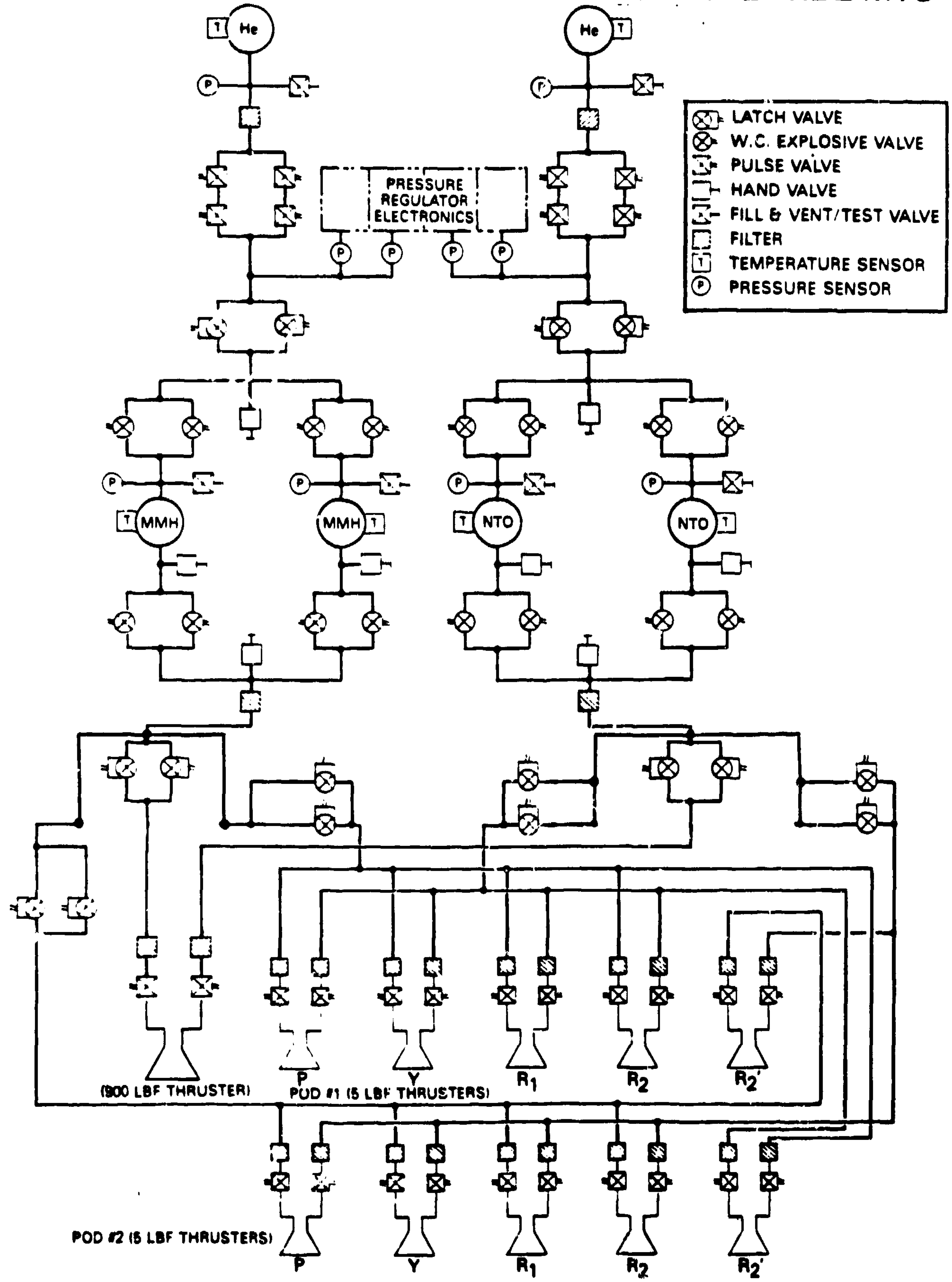

FIGURE 2

III. APPLICATION ANALYSIS AND DESCRIPTION OF COMPONENTS

A. R-40B Thruster Sizing

The basic Shuttle Primary Attitude Control Thruster is the TMC Model R-40A, 872 lbf. This thruster has a full bell nozzle area ratio (ϵ) = 22. Several scarfed nozzle versions are also used in the Shuttle where physical lengths are the same as those fo standard nozzles with expansion ratio of 120. These designs show that the basic thruster can support larger area ratio nozzles. It is desirable to use this basic thruster for the SLD translation thrust since it is a qualified component and is being produced in quantity for the Shuttle. However, an optimized nozzle should be chosen which is compatible with the available space for the thruster assembly. NRL suggested a thruster length of 26.0 inches be used for the initial studies.

Using the standard combustor R-40A (2.5 inches long), and by slightly foreshortening the control valve area of the unit by simplifying the "J" box, there is 17.17 inches in length allowable for the nozzle. The typical standard Rao nozzle of this length has an area ratio of fifty-onc. This thruster will operate at 292 pounds second/pound specific impulse at 900 pounds thrust.

Based on development tests of the prototype versions of the R-40A thruster, a longer combustor (4.0 inches) would produce an improved specific impulse. Using the overall thruster length of 26.0 inches the Rao nozzle area ratio for this unit is forty-five. This thruster is estimated to operate at 296.7 pounds second/pound specific impulse at 900 pounds thrust. The summary of initial thruster parameters for these two versions of the R-40B thruster follows:

COMBUSTOR LENGTH-IN.	NOZZLE LENGTH-IN.	NOZZLE EXIT O.D.-IN.	NOZZLE AREA RATIO-	SPECIFIC IMPULSE-SECS	FUEL FLOW LBS/SEC	OXIDIZER FLOW LBS/SEC	PROPELLANT(S) INLET PRESSURE PSIA	ESTIMATED THRUSTER WEIGHT-LBS
2.5 (Standard)	17.17	15.5	51	292	1.1855	1.8967	235	17.0
4.0	15.67	14.7	45	296.7	1.1667	1.8667	235	16.5

B. R-6C Attitude Control Thrusters

The TMC R-6C 5 pounds thrust bipropellant thruster completed the Qualification Tests for the INSAT Program. The summary of this program and the description of the thruster, together with some performance data (excerpted from the Qualification Report, MIR 736) are presented below:

"This report describes the qualification test program for the INSAT R-6C thruster (P/N 239500, S/N 001 and 002) initiated in June of 1980. This thruster is to be used in the Ford Aerospace & Communications Corporation INSAT Satellite for on-orbit satellite maneuvers. The qualification test program was performed to document the performance, thermal and structural characteristics of the flight design R-6C thruster. The tests conducted on the thrusters provided evidence and a basis for certification of the flight design in that it has met the requirements of the procurement specification (FACC document #295600).

The testing performed included an acceptance test, a qualification level vibration test and an extensive matrix of hot fire tests to demonstrate and document thruster operational capabilities within the specification envelope.

All tests were successfully completed. During the qualification program, Thruster S/N 001 accumulated 11,762 seconds of burn time and 154,257 firings. The S/N 002 thruster accumulated 11,579 seconds burn time and 166,344 firings. The longest single firing performed was 2,000 seconds in duration.

The minimum impulse bit requirement of less than or equal to .02 pound-seconds was not achieved at all system operating parameters. A minimum impulse bit at 5 milliseconds electrical pulse widths in the range of .009 to .030 lbf-seconds was achieved over the system operating parameters of 25 to 42 volts and 160 to 250 psia inlet pressures. The controlling system operating condition which affected the achievement of the .02 lbf-seconds minimum impulse bit was the input voltage to the engine. Based on the test data obtained, it would appear that the minimum impulse bit of less than .02 lbf-seconds would be achievable at voltages below 32 volts using the FACC-supplied valve driver.

Thermal tests were conducted on the thruster using both steady state and pulse firings. The results of the testing indicated that there are no duty cycles or INSAT system parameters which result in abnormal operation of the thruster. Included in these tests were restarts at maximum injector mount flange and valve temperatures, as well as operation of the thruster at various pulse cycles to thermal equilibrium."

C. Pressure Control Subsystems

Two systems for GHe pressure control were reviewed. These were the pressure regulator control and a "bang-bang" system with pressure limit sensor control.

1. Since NRL has indicated a preference and has had experience with pressure sensor control of solenoid valves, only a limited effort was made to investigate the use of pressure regulators. The Sterer Engineering Company and Consolidated Systems Corporation were contacted for a pressure regulator which would supply GHe to pressurize the propellant tankage for operation of the 900 pounds thrust engine and all ten of the 5 pounds thrust engines. This requires 52 SCFM at a regulated pressure of 270 psia. Each company has qualified regulators which would be adequate for one propellant only, i.e., these regulators would supply 26 SFCM at 270 psia. The separation of pressurization systems for each propellant has merit for reliability reasons. At this time, the further study of pressure regulators has been deferred. Cost data for one type regulator (26 SFCM) was obtained.

2. The pressure regulation system consisting of solenoid valves controlled by pressure switches was analyzed. An NRL schematic dated February 26, 1980 was used for the valve arrangement desired and is identical to those shown in Figures 1 and 2. Since a N.C. explosive valve will have essentially zero pressure drop, only the pressure drops of the other valves in the pressurizing system were considered.

   Each redundant flow path was considered to supply all of the GHe required for pressurizing one propellant. Each flow path consists of two control valves in series and one latch valve (plus the zero pressure drop explosive valve). If both the control valves and the latch valve were essentially the same size, one could divide the available total pressure drop by three to get the acceptable pressure drop for each valve.

   Calculations to determine the required valve sizes were made in the above manner. The 438 psia end tank pressure, needed for one type of pressure regulator system, was used together with the required 270 psia tank pressure to establish a system delta pressure of 168 psi. Allowing 10 psi delta pressure for tubing and fittings, 158 total or 53 psid is allowed for each valve in the system. These valves would have an equivalent orifice diameter (ESEOD) of about 0.046 inch. This means that 1/4 inch valves should be adequate for this allowable pressure drop when flowing helium.

A repeat calculation using a three valve total ΔP of 51 psi indicated that valves with ESEOD of 0.124 inch were needed. This requires a 3/8 inch or 1/2 inch nominal valve size. The tank end pressure would be 270 +51 (321) psia for valves of this size. This would permit size and weight savings for the helium tank system when compared with the tank analyzed for 438 psia end pressure.

The solenoid valves and the latching isolation valves must be designed for 3000 psia working pressure (the initial tank pressure) and a burst pressure of 12,000 psia.

D. Alternate Pressurization Systems

Historically, many schemes have been investigated to pressurize propellant tanks by means other than the direct storage of high pressure gases in order to save weight. These methods include:

- Hot gas generators - solid propellants and liquid propellants
- Heat exchangers to heat gaseous helium, nitrogen or the liquid propellant to be pressurized
- Storage of liquid helium or nitrogen and the use of heat exchangers for gasification.

A brief review of some of these systems was made to see if an alternate system could be recommended.

1. Hot gas generators are best suited to single burn, constant thrust operation. Further, the gas generator propellant feed system required is quite complex and a significant theoretical lowering of the overall propulsion system reliability thereby results when such a system is incorporated. The main propellant tanks require temperature resistant bladders to separate the hot gas from the propellant. Although stainless steel bladders have been developed for relatively small tanks development for larger tanks would be costly. The weight penalty associated with bladder tanks is significant. Therefore, the hot gas generator system was not examined in detail.

2. Cooled (-320°F) Gaseous Helium

   The use of gaseous helium cooled with a jacket of liquid nitrogen can reduce the size of the helium tank required for a given mass requirement. A heat exchanger using one of the propellants for a heat source is needed to raise the helium temperature to an efficient level. This system has advantages over a liquid helium system in that there is less required insulation and design requirements are less critical. The tank weight and volume savings could be attractive as rough calculations indicate:

For Four 54 In. I.D. Propellant Tanks

Volume Helium Tank (stored -320°F), in^3	14,945
Weight Helium - LBS	62.6
Estimated Weight of 4 Kevlar Tanks (For 3000 psi GHe Storage) 175 X 4 =	700 lbs.
Estimated Weight of One (-320°F stored GHe Tank)	398 lbs.
Estimated LN_2 required for 8 hours ground hold plus 7 days in orbit	50 lbs.
Estimated Weight savings including LN_2 penalty	248 lbs.

The above estimates are made on the basis of using one pressurant tank. This tank would be 30.6 inches in ID. The LN_2 jacket and insulation would add perhaps 2.4 inches to the tank diameter for an overall diameter of about 33 inches. If two storage tanks were required because of spacecraft spatial limitations much of the weight advantage would be lost. Note that no attempt has been made to analyze plumbing, tank support weight, spacecraft structural weights, etc. The lower volume and smaller number of tanks promote some additional savings on these items. The disadvantages of this type of system include, more complex ground equipment is required and the ground hold of Shuttle may be nonforecastable.

3. Liquid Helium

Liquid helium systems have been developed for space use. The Apollo LEM descent stage incorporated such a system. NASA Report SP-247 describes this system. The noted weight saving, in that report, of 50% is undoubtedly based on comparison between gaseous helium stored in titanium tanks and a titanium liquid helium system. The LEM liquid helium system when compared with today's Kevlar wrapped tank (which is more than 30% lighter than high pressure titanium spherical tanks) would only save about 30% of the weight. On this basis, the saving would be .30 X 700 = 210 pounds. However, this type of system is a viable alternate for the SLD system. Additional ground support equipment is required to support a liquid helium system.

4. Pressurization System Costs

The helium storage systems costs have not been fully analyzed. However, quotations have been received from the Brunswick Corporation for their Kevlar wrapped aluminum liner and titanium liner tank designs. These cost data indicate that the aluminum liner, Kevlar wrapped tank is undoubtedly the lowest cost of the systems studied.

E. Pressurant Tanks

1. The required gaseous helium for the pressurization of the propellant tanks was calculated based on the required propellant pressure, the selected size(s) of propellant tanks and a required tank end pressure. A 3% safety margin was added to the calculated GHe requirements for the 54 inch diameter propellant tanks. As requested by NRL, four pressurant tanks were sized for use with the 54 inch diameter propellant tanks. Two pressurant tanks would be used for the 42 inch diameter propellant tanks. The use of two of the tanks sized for the 54 inch propellant tanks provide an over capacity by 9.5% (including the 3% safety margin) when used with the 42 inch propellant tanks. Smaller pressurant tanks will be analyzed only if the 42 inch propellant tanks are selected for the final vehicle design.

2. The required propellant pressure at the outlets of the propellant tanks is estimated at 270 psia. This is based on analyses of the R-40B (900 lbs thrust) thruster system and the R-6C (5 lbs thrust) engines. The estimate was based on the following with both the fuel and oxidizer system pressure drops considered to be equal for the initial calculation.*

Thruster Inlet Pressure	235 psia
Lines and Fittings Pressure Loss	5 psia
Explosive Valves	0 psia
Filter - Main	5 sia
Latch Valve - Main	10 psia
Thruster Filter	5 psia
Latch Valve	10 psia

Required tank outlet pressure 270 psia.

NOTE: Tank propellant pressure heads due to spin stabilization have not been considered in this early phase of the study.

* Any differences in pressure drop between the fuel and oxidizer propellant lines will be compensated by orificing at the thrusters.

3. The pressurant tank end of mission pressure was established as 438 psia for the tank sizing calculation. This was based on the requirements of a representative pressure regulator operating to supply the proper helium flow rate at 270 psia. The current NRL preferred pressurization system is by pressure sensor controlled solenoid valves. This type of system could require a lower stored pressurant pressure at propellant exhaustion if low pressure drop valves were used. A combined valve and tank sizing analysis is necessary for the final design.

4. There are two basic designs which Brunswick produces. One is the bonded fitting concept where the inlet and outlet fittings are bonded to the basic liner spherical shell by use of a vulcanized elastomer. The other is the integral fitting concept which is a fully-machined and welded spherical liner. TMC and Brunswick investigated the bonded fitting concept for pressurant tanks to be used with nitrogen tetroxide. The standard elastomer, chlorobutyl rubber, is not compatible with nitrogen tetroxide for long periods. Since nitrogen tetroxide vapor can migrate from the propellant tanks, use of the standard elastomer is not recommended. Both DuPont Viton and Kal-rez elastomers were considered, but neither vulcanizes to metal very well. The brief review made by Brunswick and TMC left us with the belief that this concept should not be used for the SLD even though considerable cost savings are possible. The integral fitting concept is recommended at this time.

   Brunswick advises that they have investigated the outgassing characteristics of the epoxy used with the Kevlar wrap. When the tanks are temperature cycled (at 10° to 30°F higher than the epoxy cure temperature) about ten times in a vacuum, outgassing stabilizes. After the tank temperature is lowered, following stabilization cycles, to operating temperature, outgassing ceases. Specifications for pressurant tanks should include an outgassing requirement to preclude outgassing in space during the mission.

5. The required pressurant tanks to pressurize 42.0 inch ID and 54.0 inch ID tanks at 270 psia, (propellant tank ullage prepressurized to 100 psia), follow:

	For Four 42 Inch Dia. Propellant Tanks	For Four 54 Inch Dia. Propellant Tanks
Initial Pressure	3000 psia	3000 psia
End of Mission Pressure	438 psia	438 psia
GHe Total Volume including 3% margin - in^3	23,067	49,040
Number of GHe Tanks	2	4
GHe Volume Per Tank - in^3	11,533	12,260
Initial Mass of GHe at 3000 psia, 70^oF - LBS.	21.12	44.90
Final (trapped) Mass of GHe at 438 psia - LBS.	4.99	10.58
I.D. Pressurant Tank - In.	28.04(1)	28.60
Weight Estimate/Tank/ for 12,000 PSI Burst - LBS.	175	175
GHe Total - LBS.	33.15	66.3

* (1) TMC recommends use of the 28.6 I.D. tank, since four of this size tank would then be satisfactory for use with the 54 inch diameter propellant tanks.

6. Experience with the pressurant tanks for the Shuttle indicates that the lightest weight tanks are Kevlar fiber wound titanium or aluminum lined. These tanks, designed and made by the Brunswick Corp., are 30+% lighter than titanium tanks. They are also cheaper, particularly when aluminum liners are used. Therefore, only quotes for the Kevlar wrapped, aluminum liner tanks were solicited from Brunswick. Cost estimates were requested from Brunswick based on the following design parameters:

   a. Kevlar wrapped, aluminum liner.

   b. Volume 12,260 in^3, spherical shape.

   c. 3/8" inlet and outlet located at poles.

   d. Mount flanges at poles (concentric to inlet and outlet).

   e. Working pressure 3,000 psia
      Burst pressure 12,000 psia

   f. Medium, gaseous helium.

   g. Design life 7 years, temperature 70 ± 25^o.

Costs of a qualification program were requested. One hundred pressurizing cycles, a Shuttle type vibration test and a burst test - all tests on the same tank were requested.

The qualification ROM cost estimate was $200,000. Integral fitting concept tank cost estimate for four to nine units was $25,000 each, or $225,000 for nine tanks.

(For reference only - The bonded fitting concept, per the current Brunswick design was quoted at 50% of the above values.)

F. Propellant Tankage

NRL requested the use of four propellant tanks (two oxidizer and two fuel) and the study of two sizes, 42.0 inches ID and 54.0 inches ID. These tank sizes were analyzed for use with the TMC R-40B 900 pounds thrust and R-6C 5 pounds thrust (attitude control) thrusters as follows:

1. Propellant Requirements

The TMC R-40B and R-6C thrusters both use nitrogen tetroxide and monomethylhydrazine propellants at an oxidizer-to-fuel ratio of 1.6. This mixture ratio (m.r.) permits essentially equal volume tanks. At 70°F and 1.6 m.r. the fuel volume is 1.029 times the oxidizer volume. For any single tank size for both propellants, if the fuel tank ullage is set a 5% at 70°F the oxidizer tank ullage is 7.9% at 70°F. At 140°F, the ullage of each type tank is reduced to 0.8%. Since the spacecraft temperature is not expected to reach 140°F, the actual ullage will always be greater than 0.8%.

TOTAL TWO TANKS		TOTAL TWO TANKS	AT 70°F		AT 140°F	
Volume in.³	Weight Fuel-lbs.	Weight Oxidizer-lbs.	Ullage Fuel-%	Ullage Oxidizer %	Ullage Fuel-%	Ullage Oxidizer %
		42 INCHES I.D. TANKS (TWO PER PROPELLANT)				
77,584	2330	3718	5.0	8.0	0.7	0.7
		54 INCHES I.D. TANKS (TWO PER PROPELLANT)				
164,896	4953.6	7925.8	5.0	8.0	0.7	0.7

TOTAL PROPELLANT WEIGHT - FOUR TANKS

Total Propellant 42 In. Tanks = 6,048 lbs

Total Loaded Propellant 54 In. Tanks = 12,879.4 lbs

2. Procurement specifications were established. These were based on specific requirements by NRL, the initial chosen propellant system supply pressure of 270 psia, a typical vibration spectrum, and NASA safety standard NSS/HP 1740.1. Figure 3 summarizes the requirements which were mailed to five tank vendors for quotation and data. Both Titanium (Ti-6Al-4V) and aluminum (6061) materials were investigated. Non-recurring cost estimates cover tooling and the qualification program, including vibration and bursting of one tank. Recurring cost estimates include nine deliverable tanks, two sets plus one spare. Rough order of magnitude cost (mid 1980 $) and weight data follow:

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NAVAL RESEARCH LABORATORY SLD
REACTION CONTROL AND PROPULSION SYSTEM
PROPELLANT TANKS

1. Required number of tanks - 9 deliverable plus one for qualification.

2. Number of tanks/system - four, two nitrogen tetroxide and two monomethyl-hydrazine - all of the same size and design.

3. Size (Two Quotes)
   A. 42.0 inches ID, spherical
   B. 54.0 inches ID, spherical

4. Material Ti-6Al-4V with Ti to 304L CRES inlet and outlet transition tubes.

5. A. Inlet (1 inch diameter tube) and outlet (1 inch diameter tube) in polar positions. The inlet shall have a concentric trunnion type tank support one inch in length with whatever necessary diameter.

   B. On the 54.0 inch tank <u>only</u>, provide a minimum length 90° fitting at the propellant outlet. (Minimum height from tank circumference to the top of the fitting-tube to be 90° from the polar axis.)

6. The girth weld and adjacent tank mount ring (or alternative mount lugs) shall be positioned 45° to the polar axis.

7. Working Pressure 280 $\pm$10 psia
   Burst Pressure 560 $\pm$10 psia
   (Safety factor nominally 2.0)
   Collapse Pressure 15 $^{+1.0}_{-0}$ psid

8. "G" rating all axes - 8.8 g's.

9. Vibration spectrum (initial for quotation)

FREQUENCY	RMS ACCELERATION	POWER SPECTRAL DENSITY g^2/Hz	POWER SPECTRAL DENSITY db/Octave
Hz	g's		
20-50			+6
50-800	12.5	.125	
800-2000			-6

FIGURE 3

10. Tank mounting method - full flange or mounting lugs (10 minimum) located 45° from the polar axis.

11. Cost quote to include all detail design with full stress analysis and fracture mechanics analysis. Fracture mechanics analysis to include assurance of compatibility with the safety factor as initially chosen.

12. Full qualification including vibration test and the bursting of one tank.

13. Tank to comply with requirements of reliability and QA specification and NASA safety standard NSS/HP 1740.1. (Advise on exceptions, if necessary).

14. Protective covers to be installed on deliverable tanks.

15. Cost quotations to be based on an order date of November 1980.

    A. Provide the best realistic delivery and qualification test completion schedule without the use of premium manhours or D.C. dollars for five deliverable plus the qualification program.

    B. Deliver the last four tanks within six months of A.

16. Provide the approximate weight of each tank size.

    A. Per Item 7 above.

    B. Deleting the collapse pressure requirement.

FIGURE 3 (Cont)

42.0 INCH I.D. SPHERICAL TANKS - Ti-6Al-4v MATERIAL

COMPANY	DELIVERY ARO - MONTHS	NON-RECURRING COST $	RECURRING COST $	WEIGHT LBS
1. Airite Division Sargeant Industries El Segundo, CA	36	566,000	1,188,000	Non-Vacuum Stressed 41.0 Vacuum Stressed 44.6
2. Pressure Systems, Inc Los Angeles, CA	36	487,000(1)	1,350,000	Non-Vacuum Stressed 56 Vacuum Stressed 68
3. Fansteel Precision Sheet Metal Los Angeles, CA	33	602,083	1,289,618	Non-Vacuum Stressed Estimate 40

(1) Vibration and shock testing is not included.

54.0 INCH I.D. SPHERICAL TANKS - Ti-6Al-4V MATERIAL

	COMPANY	DELIVERY ARO - MONTHS	NON-RECURRING COST $	RECURRING COST $	WEIGHT LBS
1.	Airite Division Sargeant Industries El Segundo, CA		No Bid At This Time		
2.	Pressure Systems, Inc Los Angeles, CA	36	627,000(2)	1,800,000	Non-Vacuum Stressed 107 Vacuum Stressed 131
3.	Fansteel Precision Sheet Metal Los Angeles, CA	33	910,927(3)	1,871,417(3)	No Estimate

(2) Vibration and shock testing is not included.
(3) Based on a go-ahead 11/1/80 and the use of government-furnished propellants or test fluids.

54.0 INCH I.D. SPHERICAL TANKS - 6061 ALUMINUM MATERIAL

	COMPANY	DELIVERY ARO - MONTHS	NON-RECURRING COST $	RECURRING COST $	WEIGHT LBS
1.	Airite Division Sargeant Industries El Segundo, CA	22(3)	433,000(4)	387,000(4)	Vacuum Stressed 206

(3) Based on a 16 weeks estimate for material delivery.
(4) TMC's opinion is that these values are too low by at least 25%.

G. Control Components

Propellant and pressurant control components for the SLD were sized for efficient functioning when operating with the R-40B and R-6C thrusters and with the chosen tankage. An NRL system schematic dated 2/26/80 was used to determine the quantity and type of components needed. A safety factor of four times the operating pressure was set for each component. Vendor companies were then contacted for available and, in-so-far as possible, qualified components which met these requirements. Cost and delivery estimates were obtained. These costs are usually in mid-1980 dollars. In accordance with the NRL requirements, component connections were requested to be removable and all external seals were to be dual seals to eliminate single point failures.. Brief descriptions and cost information for these components are provided herewith.

1. Pressurant Fill and Vent Valve

A 1/4 inch line size fill and vent valve for each of the two helium systems per SLD were chosen. The Pyronetics Devices, Inc. valve P/N 1831 is fully qualified. It has a redundant sealing cap which is installed after servicing the vehicle.

COMPANY	PART NUMBER	QUANTITY	FIXED PRICE COST BID - $
Pyronetics Devices, Inc. Denver, CO	1831	7	2,796 each

Delivery was quoted as 6 months ARO.

2. Propellant Fill and Drain Valve

An arbitrary 1/2 inch line size, manually operated, valve was chosen as a reasonably low pressure drop unit which, being relatively small, would be light weight. The Pyronetics P/N 1846 is fully qualified for several space programs. The "O" ring seal was suggested by TMC to be made of DuPont Kal Rez. This is the best known elastomer for nitrogen tetroxide resistance other than Teflon. The valve will need some requalifying for the new seal. This cannot be done by the valve vendor. A sealing cap provides the required redundant seal. Three sets plus one spare valve, or a total of 13 valves, were cost estimated for each propellant.

COMPANY	PART NUMBER	QUANTITY	FIXED PRICE COST BID - $
Pyronetics Devices, Inc. Denver, CO	1846	26	2,151 each

Delivery was quoted as 6 months ARO.

3. Helium Filter

One filter was incorporated for each helium system. The following design parameters were established:

a. Flow rate 52.6 scfm, at 270 psia minimum.

b. Inlet and outlet 3/4" tube
Removeable connections, but not dual seal.*

c. Rated pressure 3,000 psia, Burst pressure 12,000 psia

d. Pressure drop < 5 psid

e. Materials 304L CRES.

f. Filtration 20 micron absolute.

Cost data follows:

COMPANY	PART NUMBER	QUANTITY	ROM COST - $
Wintec Division of Brunswick Corp. Los Angeles, CA	(NOTE: Fabrication to be to NRL drawing and specifications)	3 or more	677*

*NOTE: A second seal at the inlet and outlet is estimated to add $200.

Delivery was quoted as 20 weeks ARO

4. Propellant (Nitrogen Tetroxide or Monomethylhydrazine) Filter - Large

As shown on the schematic, there are three large filters (suitable for the R-40B thruster flow rates) per propellant system. The following design parameters were established for these filters.

a. Flow rate 10.4 gpm.

b. Inlet and outlet tubes one inch diameter.

c. Rated pressure 300 psia, Burst pressure 1,200 psia.

d. Pressure drop <1 psi.

e. Materials 304L CRES.

f. Filtration 20 micron maximum.

Cost data follows:

COMPANY	PART NUMBER	QUANTITY	ROM COST - $
Wintec Division of Brunswick Corp. Los Angeles, CA	(NOTE: Fabrication to be to NRL drawing and specifications)	4 or more	1100* each

*NOTE: A second seal at the inlet and outlet flanges was not included. An additional cost of $300 for each unit is estimated for these seals.

Delivery is estimated at 9 months ARO.

5. Propellant Filter - Small

Two in-line (1/4" tube) filters are shown for each propellant at each 5 pound thrust unit. These filters at .06 gpm would have a maximum of 2 psi pressure drop, according to the vendor, Western Filter and are rated at 10 microns. Cost data follows:

COMPANY	PART NUMBER	QUANTITY	ROM COST - $
Western Filter Chatsworth, CA	T-4	26-50	29.00
		26-100	26.00

Delivery was 2 months ARO.

6. Helium Pressurization Control Valves

The use of series-parallel control valves in each propellant system to provide helium pressure control is shown in the schematic. Initial effort was made to obtain data on qualified valves which had very low pressure drop. Thus, 1/2 inch nominal size valves were chosen. Subsequent calculations indicated that 3/8 inch or 1/4 inch valves may be adequate if a pressure drop of about 50 psi can be allowed. Data is presented herein on the 1/2 inch valves only. The design criteria established for these valves follow:

0-3000 psi working pressure and 12,000 psia burst pressure

Seals to be compatible wth nitrogen tetroxide or monomethylhydrazine or hydrazine vapors.

A requalification program to include basic Shuttle vibration, leak tests, cyclic life test (goal 250,000 cycles).

The Valcor Engineering Corporation advised that their 680 series valve has an equivalent orifice diameter of 0.26 inch. The response is 55-60 msecs, $C_V = 1.5$ and the power requirement is 1.2 amperes at 30V. It is qualified for 100,000 cyclic life. Their standard valve is designed to meet a 7500 psia burst pressure.

Cost data was obtained as follows:

COMPANY	PART NUMBER	QUANTITY	BURST PRESSURE psia	UNIT COST - $
Valcor Engineering Corp.	1/2" Series 680	18	7,500	898
Springfield, NJ	1/2" Series 680	28	7,500	795
	1/2" Series 680	18	12,[illegible]	1200 est.
	1/2" Series 680	28	12,0[illegible]	1080 est.
	Requalification Program			$18,000 est.

*NOTE: The above costs are using Viton "O" rings, "but Valcor cannot guarantee service with nitrogen tetroxide fumes."

Delivery estimated 9 months ARO.

7. Helium Solenoid Isolation Valves

The solenoid isolation valves shown in the schematic might be the same valve as described in Item 6 above, the Valcor Series 680, but the "O" rings and seat material assured to be N_2O_4 resistant. The 28 quantity under the cost data considers 18 valves will be for the pressurization control and ten valves will be for the isolation function. However, a latching valve is more preferable (to minimize power) to a solenoid valve.

8. Pressurant Isolation Valve, N.C. Explosive

Complete isolation of the propellant systems from the pressurant supply is assured by the use of two explosive-type valves in parallel for each propellant tank. These valves also isolate the propellant tanks from one another during the storage period. The following design criteria were established for this valve:

a. Valve to be used with nitrogen tetroxide, monomethylhydrazine, or helium.

b. 3/4 inch tube size, $C_V = 5.94$ or greater.

c. Stainless steel construction.

d. 300 psia working pressure, 1,200 psia burst pressure.

e. Inlet and outlet connections to be removeable type with redundant leakage seals.

f. Initiators to be included.

Cost data was obtained as follows:

COMPANY	PART NUMBER	QUANTITY	UNIT COST - $
Siebel Air Los Angeles, CA	3434-2	18	1,230

Delivery, 4 months ARO.

9. Propellant Hand Valve

The NRL schematic showed three (now four) hand valves per propellant. Wright Components, Inc. was contacted for valves which would handle nitrogen tetroxide or monomethylhydrazine. They had not had experience with the oxidizer but concluded the seat material should be Kal Rez. The cost estimates herein do not cover the necessary qualification of these valves with the new material. All leakage paths will be double sealed. TMC agrees this material (or Teflon) may be the best for the purpose.

Cost data follows:

COMPANY	PART NUMBER	QUANTITY	UNIT COST - $
Wright Components, Inc. Clifton Springs, NJ	12183	9 13 26	1,677 1,540 1,270

Delivery, 9 months ARO

10. Propellant Isolation Valve, N.C. Explosive

As shown on the NRL schematic, two pairs of propellant isolation valves are used for each propellant. The Siebel Air P/N 3434-2 valve, covered in Item 8 above, is satisfactory for propellant isolation. The 3/4 inch size was chosen as adequately large for low pressure drop, especially since only one-half of the flow rate would be flowing through any one valve. (One-half from each of the paired propellant tanks.)

11. Propellant Latch Valve - Main

Dual latch valves are shown on the schematic for each propellant. Valcor Engineering Corp. made suitably sized latching valves for the Apollo program. These valves have the following characteristics:

Series 472

Hydrazine (or MMH) valve, 3/4 inch size
500 PSIA working pressure, 2000 PSIA burst pressure
Equivalent orifice diameter 0.41 inch
24-32V operation

Series 277

Nitrogen tetroxide valve, 3/4 inch size
500 PSIA working pressure, 2000 PSIA burst pressure
Equivalent orifice diameter 0.41 inch
24-32V operation

Dual seals were requested to be added to the inlet and outlets; these are included in the following cost data:

COMPANY	PART NUMBER	QUANTITY	UNIT COST - $
Valcor Engineering Co.	Series 472 (MMH)	7	1,580*
Springfield, NJ	Series 277 (N_2O_4)	7	2,470*

* These costs do not include special cleaning or environmental tests or adherence to any special NRL specifications. An additional $200 each is suggested to cover these probable costs

Delivery - estimated 9 months ARO.

12. Propellant Latch Valve - 5 Lbs Thruster

A. Latch valves are shown for each 5 pound thruster and each propellant. TMC produces a fully qualified 1/4 inch size latching valve for use with nitrogen tetroxide and monomethylhydrazine. They are being used on the INSAT and LEASAT programs. Modifications to the inlet and outlet would be made to include flanged connections which incorporate the required dual seals. These changes are included in the cost estimate which follows:

COMPANY	PART NUMBER	QUANTITY	ROM - 1980$ UNIT COST
The Marquardt Company	239775	5	9,000
Van Nuys, Ca.		7	

B. Other companies were contacted for a 1/4 inch latch valve. Wright Components Inc. have a basic 1/4 inch valve. They have not had experience with the proper materials for use with nitrogen tetroxide. They had tentatively selected Kal-Rez for the seat material. A requalification of these valves would be recommended when the new seat material has been finalized and subsequent to life test evaluation with propellant. The Wright P/N 15875 Valve, Solenoid detenting, modified to provide double sealed inlet and outlet and incorporating the Kal-Rez seat has been cost estimated
by Wright as follows:

COMPANY	PART NUMBER	QUANTITY	UNIT COST - $
Wright Components, Inc.	15875	5	5,900*
Clifton Springs, NJ	15875	7	5,400

Delivery 9 months ARO

*Estimated from quantity orders of 43 and 64

IV. RECOMMENDATIONS

The studies and investigations described in the foregoing sections of this report have been purposely a preliminary survey of a bipropellant propulsion system application to the Shuttle Launch Dispenser (SLD) mission. A more detailed study will be required before initiating the design and development of the propulsion stage of the SLD. It is recommended that a follow-on activity be initiated to include:

- Prepare detailed procurement specifications for components, propellant tanks, pressurant tanks and thrusters and obtaining firm cost and delivery data.
- Prepare an R-40B Thruster preliminary Qualification Test Plan.
- Prepare a preliminary Thermal Analyses of the R-40B Thruster installation into the SLD. Determine the required insulation to protect the structure and other components.

- Establish the preliminary design of the five unit RCS cluster assembly.
- Make a preliminary propulsion system FMEA and hazards analysis based on NASA payload equipment safety requirements and NRL ground handling requirements.